



End-To-End Simulations with SIXTE

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<https://www.sternwarte.uni-erlangen.de/research/sixte/>

What are End-to-End Simulations?

End-to-end (e2e) simulations: Simulation of the full detection chain for an astronomical instrument, from the astrophysical source through the imaging and detection process to the final data product.

⇒ Full model of observational setup

E2e simulations have two major “customers”:

Scientists:

- Gauge **effect of design onto science**: Can science goals be reached with the instrument?
e.g., imaging quality, spectroscopy, . . .
- What other “observatory” science is possible?
- Plan future observations

Instrumentalists:

- Use **science examples to study design**: What is impact of design onto science goals?
- Translation of instrument parameters \longleftrightarrow Science goals
- Estimate instrument performance
e.g., telemetry constraints, CPU constraints

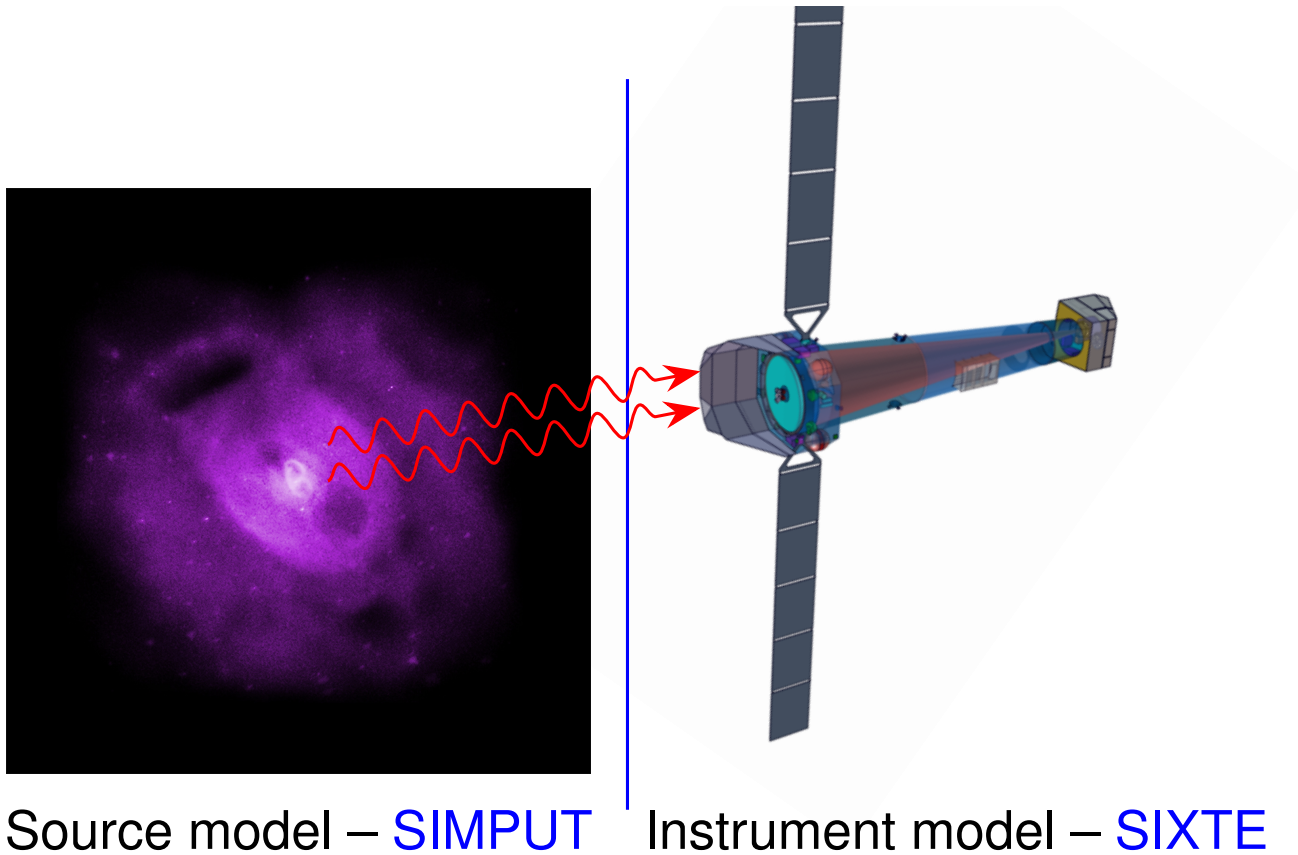
⇒ **Core component of mission design and implementation!**

To be useful, e2e software should always represent best understanding of real instrumental performance.



What is SIXTE?

Modeling

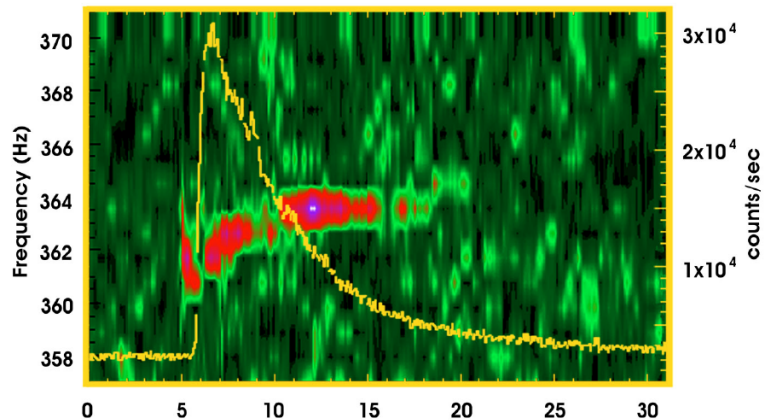
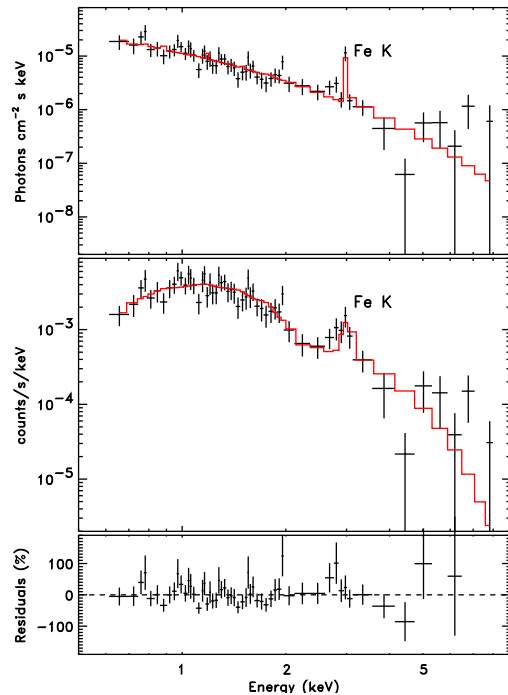
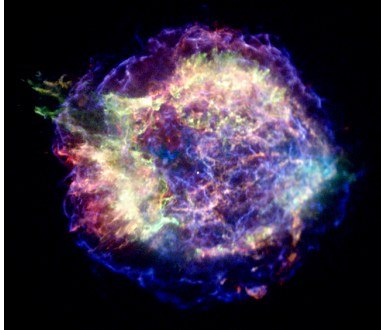
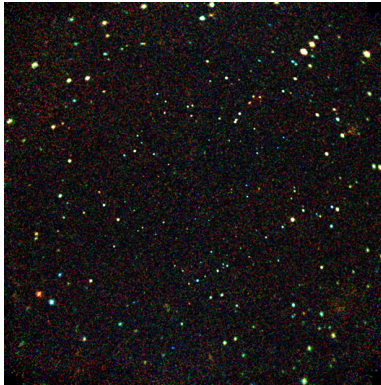


Source model: Define **properties of the sources:** Positions, Extended source/point source, spectral shape, variability,...

Instrument model: Define **properties of the instrument:** Imaging parameters, detection process, data processing chain

Output: Data that can be analyzed using **standard astronomical analysis software** (FTOOLS, XMM-SAS, XSPEC, ISIS,...)

Source Model: SIMPUT



sources are characterized by:

- source properties:
 - spectral shape
 - positions
 - light curves, pulse profiles, power spectra...
 - spatial extent
 - photon lists from MHD simulations
 - “data cubes” (e.g., cosmology)
- format allows **reuse of common properties of sources**
 - e.g., reuse AGN spectra for multiple sources, reuse images of extended sources,...
- catalogs with **arbitrary number of sources**
 - scales to millions of sources
- compatible w/other simulators
 - simx, MARX

SIXTE

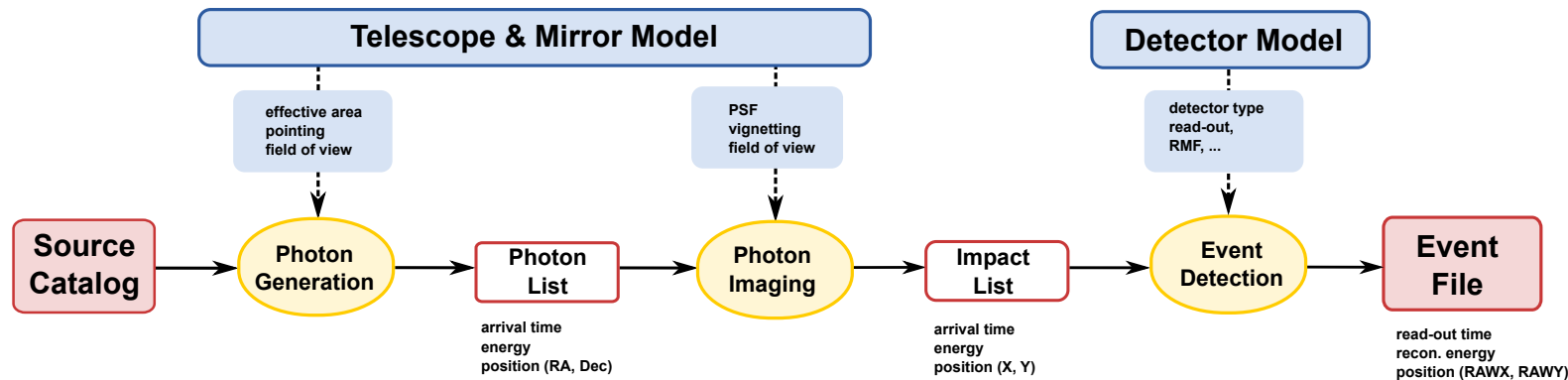
e2e environment: **SIXTE**, a generic **Monte Carlo** simulation framework for X-ray instruments

(**Athena**, eROSITA, ARCUS, XMM, LOFT, IXO, GRAVITAS,...)

<http://www.sternwarte.uni-erlangen.de/research/sixte>

- **modular** software → reuse existing algorithms for multiple instruments
- **command line** driven for longevity

we will show how to script SIXTE with bash and python

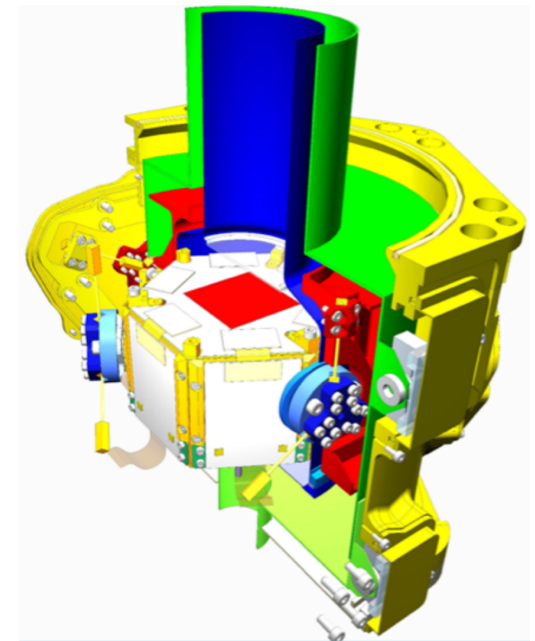
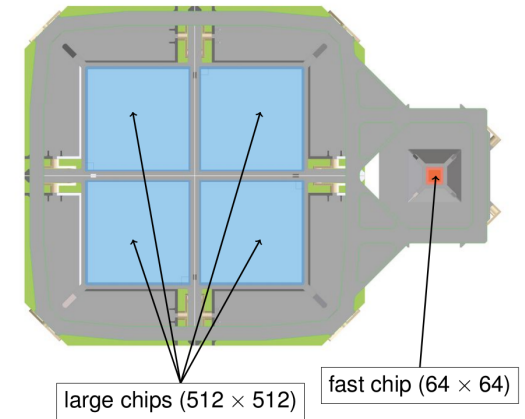


- uses **calibration data** (response files, PSF, ...) or **physics-based instrument model**
- **output: FITS event list** (time, energy, pixel)

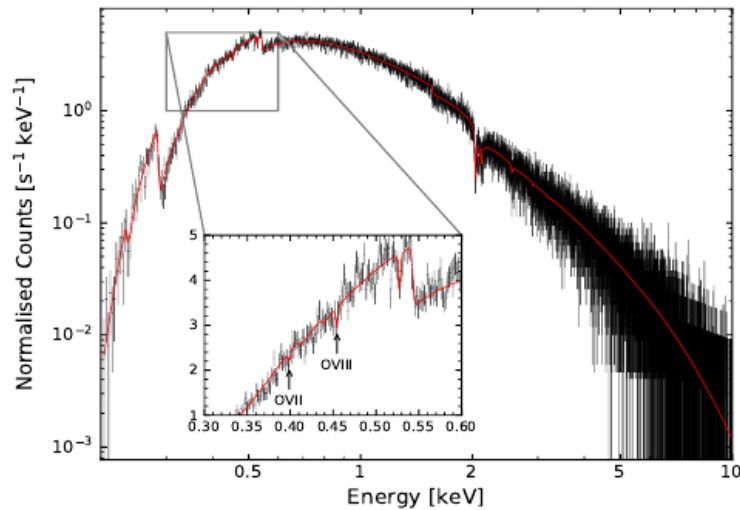
⇒ **one simulator for science & technology development**

Instrument model

- **Imaging module**
 - pointing (attitude, e.g., for dithering)
 - ARF
 - vignetting
 - PSF
- **Instrument module**
 - device simulator:
 - **simple/fast simulation:** RMF sampling
 - **advanced simulation:** physics
(e.g., $T(t)$ for X-IFU, photon effects in Si for WFI)
 - flexible focal plane description (XML)**
 - other effects considered: pile-up, crosstalk, **background**, readout
- **Output:** FITS event files

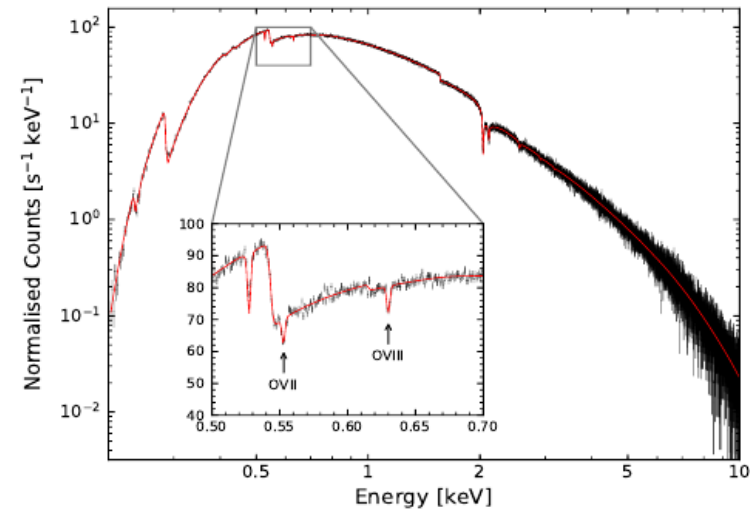


Example: GRBs and WHIM

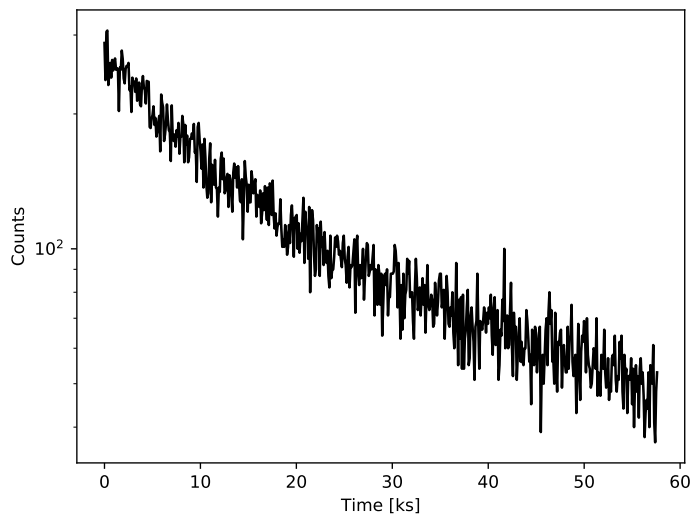


$$z_{\text{WHIM}} = 0.4388$$

Walsh et al. (2020, A&A 642, 24; GRB is at $z = 2$)



$$z_{\text{WHIM}} = 0.0382$$

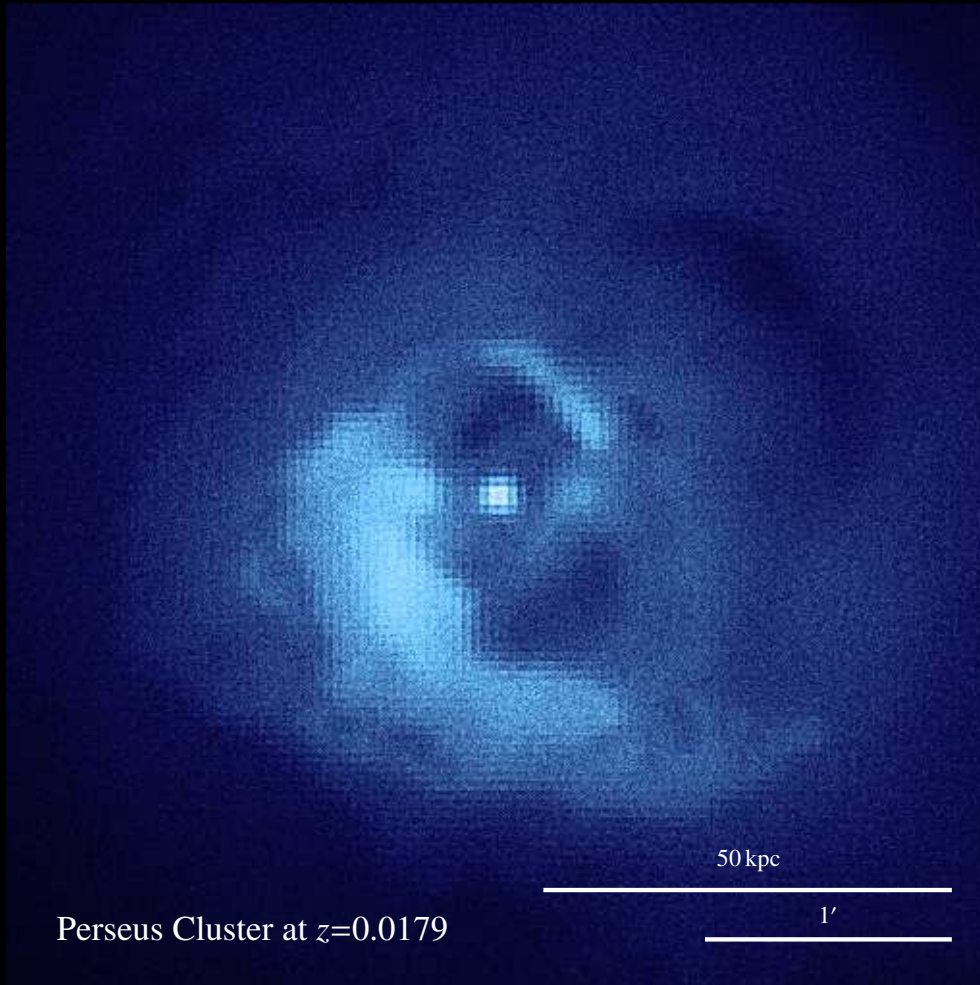


Example: Detection of Oxygen lines from WHIM in GRB spectra

Uses:

- realistic lightcurve
- realistic spectral shape

Simulation Output



50 ks, one chip

Now shift cluster to higher z :

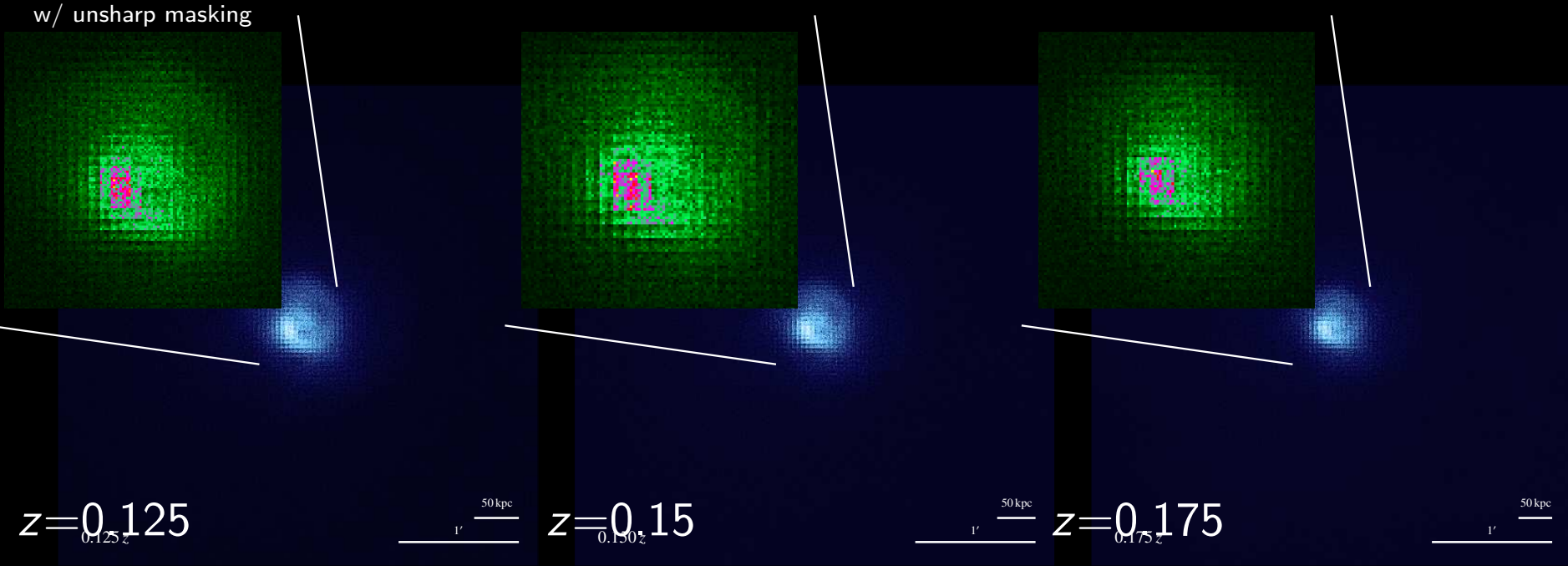
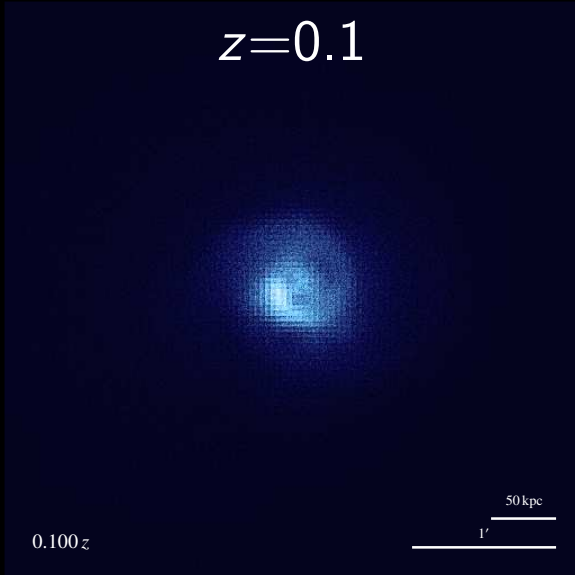
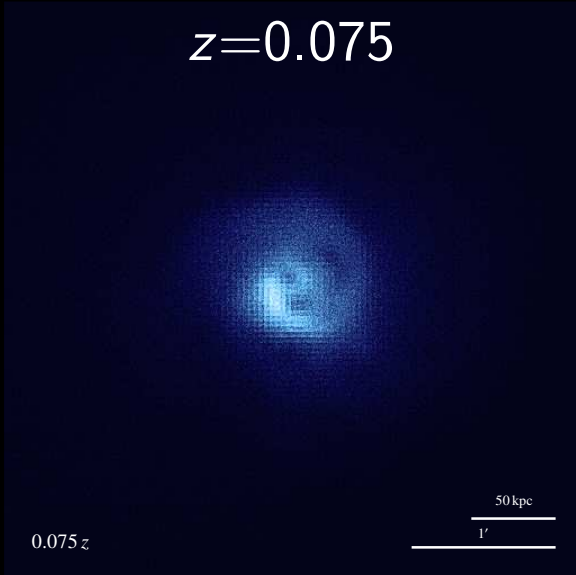
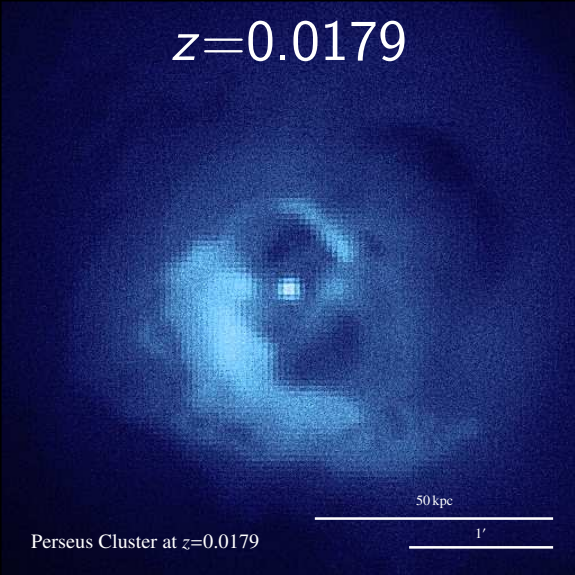
1) Scale cluster size scale via:

$$\phi(z) = \phi_{\text{pers}} \cdot \frac{D_{\text{pers}} / (1+z_{\text{pers}})^2}{D(z) / (1+z)^2}$$

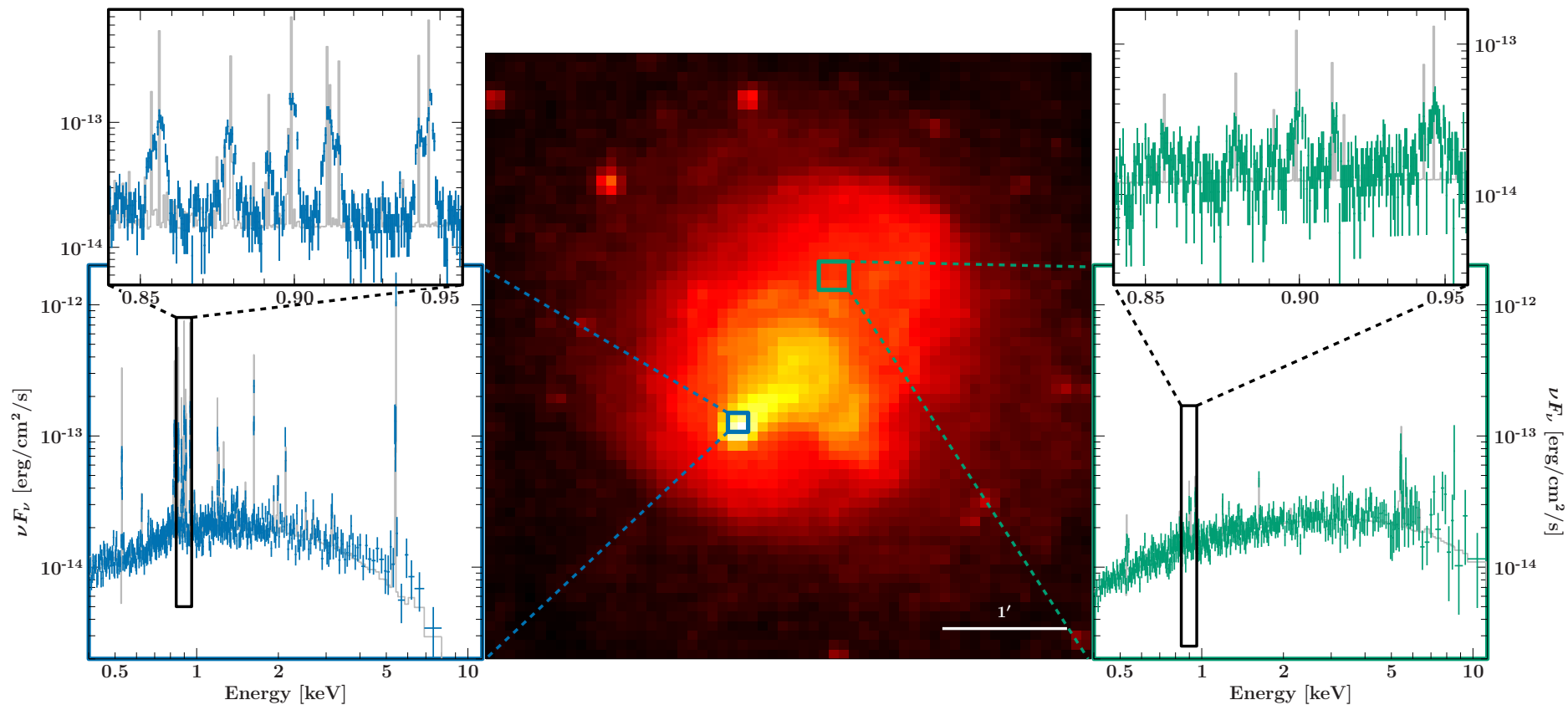
2) Scale flux with luminosity distance:

$$F(z) = F_{\text{pers}} \cdot \left(\frac{D_{\text{pers}}}{D(z)} \right)^2$$

Simulation Output

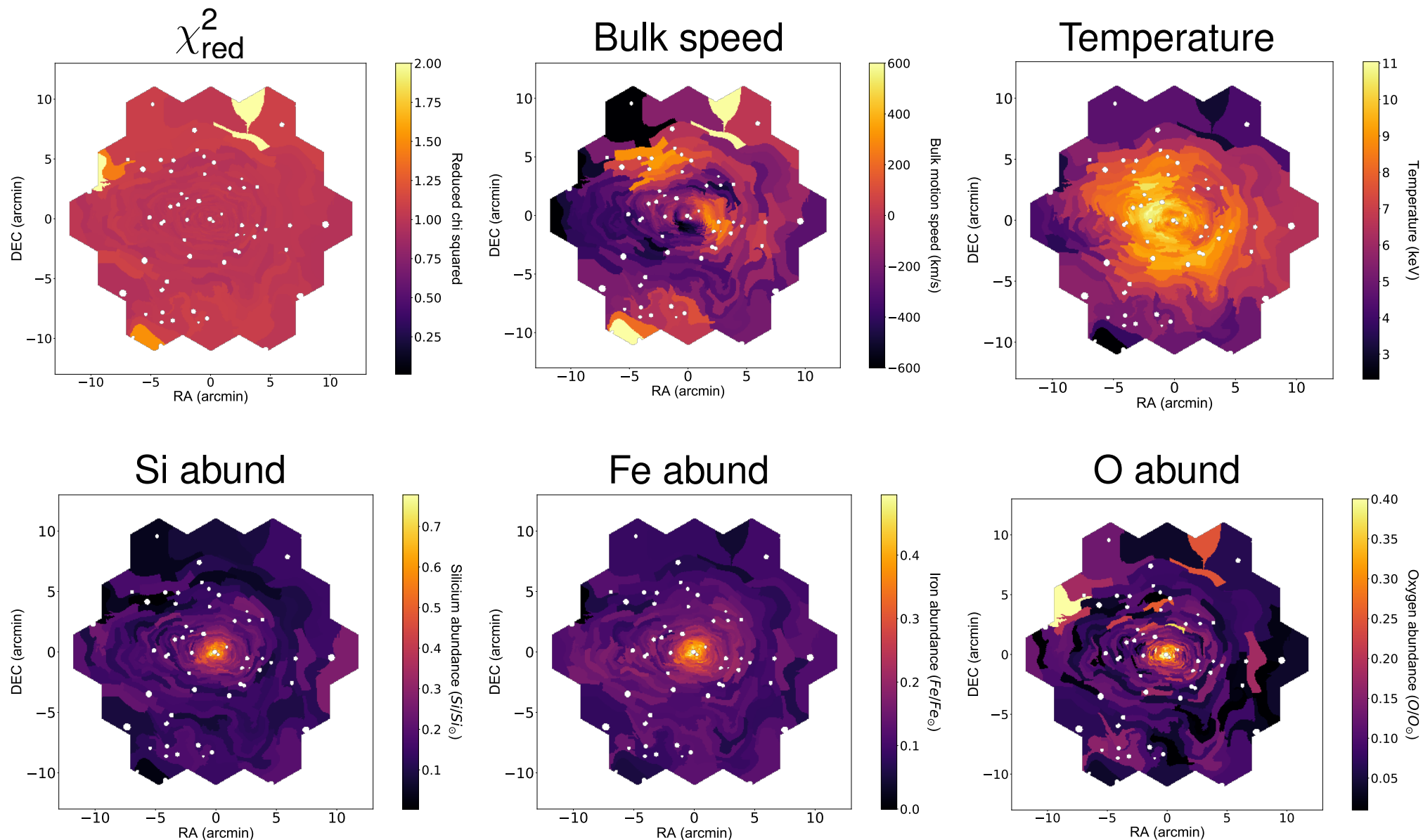


Example: Galaxy clusters



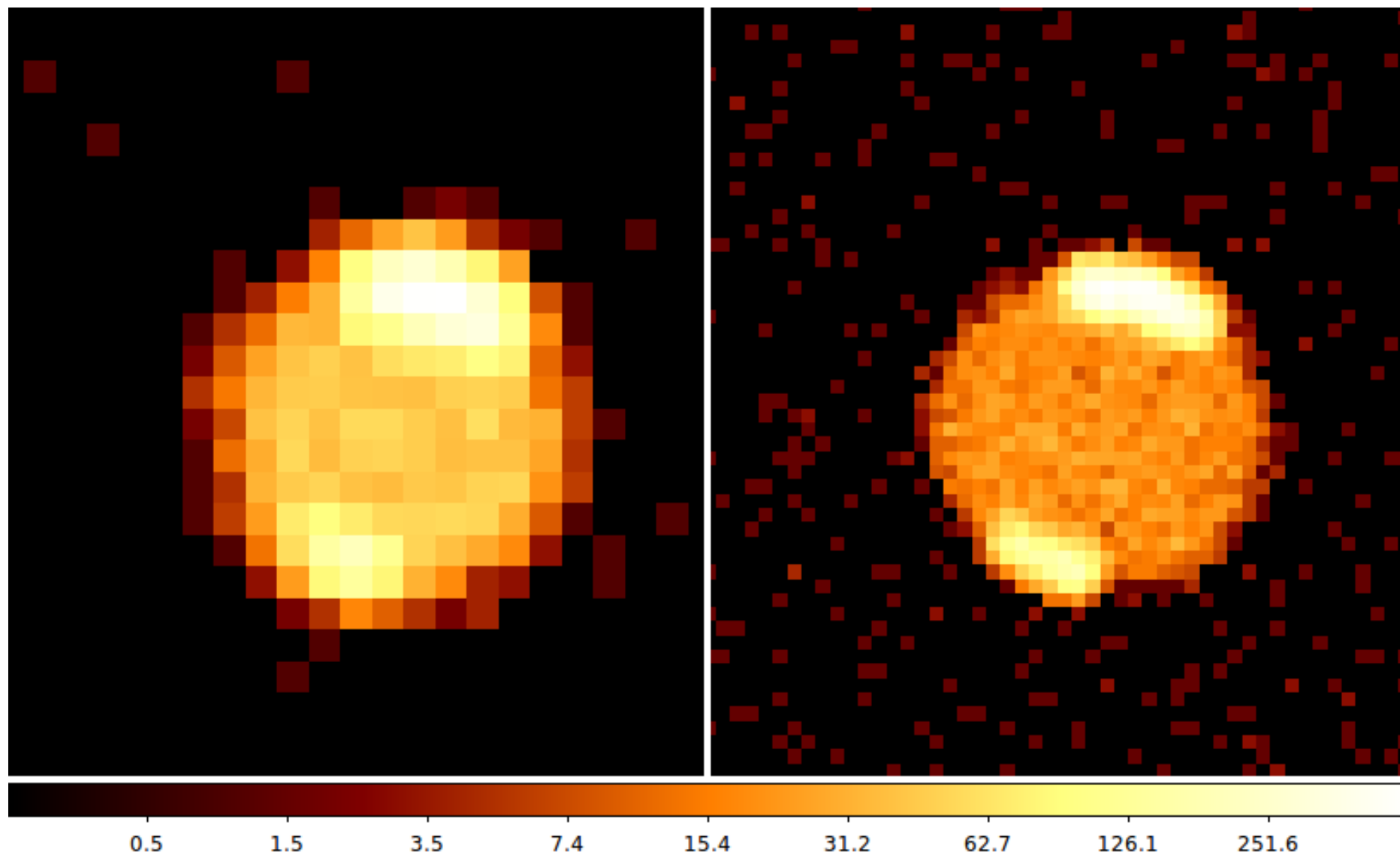
Abell 2146 with X-IFU (T. Dauser/E. Pointecouteau)

Example: Galaxy clusters



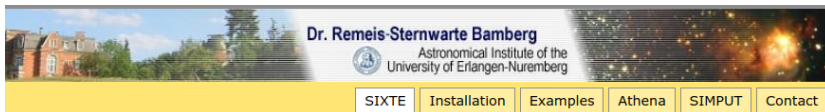
after E. Cucchetti et al. (2018, A&A 620, 173)

Example: Jupiter



Jupiter in the WFI and the X-IFU (C. Kirsch / G. Branduardi-Raymont)

Summary



SIXTE - Simulation of X-ray Telescopes

SIXTE is a software package for X-ray telescope observation simulations developed at the Remeis Observatory (ECAP). It allows to undertake instrument performance analyses and to produce simulated event files for mission- and analysis studies.

The software strives to find a compromise between exactness of the simulation and speed. For many cases, by using calibration files such as the PSF, RMF and ARF, efficient simulations are possible at comparably high speed, even though they include nonlinear effects such as pileup. Setups for some current and future missions such as XMM-Newton or Athena are included in the package, others can be added by the user with relatively little effort through specifying the main instrument characteristics in a flexible, human-readable XML-based format.

For an overview of the SIXTE software package, see [Dauser et al. \(2019\)](#). If you use results obtained with SIXTE in a publication, please cite as: "This research has made use of the SIXTE software package (Dauser et al., 2019) provided by ECAP/Remeis observatory (<https://github.com/thdauser/sixte>)."

SIMPOT Format - Source Description

Properties of X-ray sources to be simulated are described in a detector-independent format, i.e., the same input can be used for simulating observations with all available instruments, and the same input can also be used for simulation with the SIMX simulator. The input files can be easily generated from standard data such as XSPEC spectral models or FITS images with tools provided with the SIXTE distribution. The input data scale well from single point sources up to very complicated setups. For example, for ATHENA we have simulated observations of the galactic center based on the Chandra input catalogues and images of the diffuse emission, while for eROSITA we regularly perform simulations of the whole sky using several million time-variable point sources.

More details on the SIMPUT format are described [here](#). We also provide selected SIMPUT files for [download](#), which can be readily used in a Sixte simulations.

SIXTE Simulator Manual

The first version of the SIXTE simulator manual is available for download below. It includes general description of SIXTE and the implementation of detectors such as the WFI, X-IFU, eROSITA and others. In addition, tutorials for Athena WFI and X-IFU simulations are included.

download: [simulator_manual.pdf](#) (v1.3.10, 2019-11-15)

supplementary files for the X-IFU tutorial (30MB): [X-IFU_clusters_tutorial.tgz](#)

4 year eROSITA Attitude file for a launch in April 2019 (200MB): [eRASS_4yr_epc85_att.fits.bz2](#)

4th SIXTE Workshop (19.-21. February 2019, IFCA)

On the 19. until 21. February 2019 the fourth SIXTE workshop took place in Santander, with a focus on Athena WFI and X-IFU simulations. Below is a selection of the talks presented there.

SIXTE MANUAL
Ref.: SIXTE-MANUAL (v1.3.10)
Date: 15 Nov 2018
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10.7 Simulations of Galaxy Clusters with the X-IFU

10.7.1 SIMPUT file for 3D data

10.8 How to run and analyse an X-ray Integral Field Unit (X-IFU) simulation

10.9 How to run a simulation with lesson

10.9.1 Used SIXTE tools in this section

Access:

- **documentation:** 96 p. manual and Dauser et al. (2019, A&A 630, 66)
- **help desk:** sixte-support@lists.fau.de
- **Source code:** <http://www.sternwarte.uni-erlangen.de/research/sixte>.

Works on Linux and Mac, git and release versions; also available on JHU sciserver



When to SIXTE?

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When not to use SIXTE:

but fakeit or similar tools

- fainter point sources ($\lesssim 1$ mCrab)

$$1 \text{ mCrab: } F_{0.5-2\text{keV}} = 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1},$$
$$F_{2-10\text{keV}} = 2 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1},$$

unless background starts to become important

- quick estimates

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When to use SIXTE:

and *not* `fakeit`

- bright sources ($\gtrsim 10$ mCrab)

i.e., many “famous” AGN

- faint sources if background or exposure map matters

- imaging simulations:

galaxy clusters, AGN evolution, . . .

- point source detection sensitivity
- point sources in crowded fields
- extended sources

- variability simulations

e.g., reverberation mapping, pulsations, QPOs, . . .



How to SIXTE?

This workshop

This workshop:

- Introduction to SIXTE with emphasis on ATHENA
- Software oriented, mixes instrument descriptions with (many) tutorials
- Based on gather town, zoom, SciServer
- Presentations will be recorded

Taught by people with experience in SIXTE:



Thomas Dauser



Lea Michalski



Christian Kirsch



Max Lorenz



Ole König



Maite Ceballos